Neutralino polarization effect in the squark cascade decay at LHC[a]

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ABSTRACT

We study the effect of the neutralino polarization in a squark cascade decay $\tilde{q} \to q\tilde{\chi}_2^0 \to ql^{\pm}\tilde{l}^{\mp} \to ql^{\pm}\tilde{l}^{\mp} \to ql^{\pm}l^{\mp}\tilde{\chi}_1^0$. Charge asymmetry in the lepton-jet invariant mass distribution appears depending on the chirality structure of the sfermion-fermion-neutralino coupling. With use of the Monte Carlo simulation, we show that the asymmetry is measurable in LHC. We also show that the distribution of the charge asymmetry is sensitive to the (s)lepton flavor.

1. Introduction

One of the important objectives in the LHC experiments is to obtain the information about the interactions of the SUSY particles. In this work [1], we study the following squark cascade decay process

$$\tilde{q} \to q\tilde{\chi}_2^0 \to ql_1^{\pm}\tilde{l}^{\mp} \to ql_1^{\pm}l_2^{\mp}\tilde{\chi}_1^0, \tag{1}$$

and investigate if SUSY study at the LHC can provide an information on the chiral nature of the sfermions.

Due to the chirality structure of the squark-quark-neutralino coupling, the $\tilde{\chi}_2^0$ is polarized. The polarization of $\tilde{\chi}_2^0$ then affects the angular distribution of the slepton in the neutralino decay. The polarization dependence of the angular distribution eventually shows up in the charge asymmetry in the $m(ql_1^{\pm})$ distribution, because the polarization dependent part of the amplitude flips under the charge conjugation transformation [2].

We study the charge asymmetry in the minimal supergravity (mSUGRA) model, taking account of the slepton left-right mixing effect. We show that the charge asymmetry, as well as the $\tilde{\chi}_2^0 \to l\tilde{l}$ branching ratio, depends on the lepton flavor $l = e$, μ or τ. We perform a Monte Carlo simulation to demonstrate the detectability at the LHC.

2. Decay Distribution and Charge Asymmetry

The sfermion-fermion-neutralino interaction Lagrangian is written as

$$\mathcal{L} \;=\; -\frac{g_2}{\sqrt{2}}\sum_{i,\alpha}\bar{\tilde{\chi}}_i^0\left(L_{i\alpha}^f\frac{1-\gamma_5}{2}+R_{i\alpha}^f\frac{1+\gamma_5}{2}\right)f\tilde{f}_\alpha^* + \text{H.c.}, \tag{2}$$

where $f = q, l$ ($\tilde{f} = \tilde{q}, \tilde{l}$) refers to quark (squark) and lepton (slepton) fields. $i = 1, 2, 3, 4$ and $\alpha = 1, 2$ are the suffices for the mass eigenstates of the neutralinos and the sfermions,

[a]Talk based on the work [1], presented at the 12th International Conference on Suypersymmetry and Unification of the Fundamental Interactions (SUSY04), June 17-23, 2004, in Epochal Tsukuba, Tsukuba, Japan.

respectively. g_2 is the SU(2) gauge coupling constant. The coefficients $L^f_{i\alpha}$ and $R^f_{i\alpha}$ are determined by the SU(2)×U(1) gauge couplings, the Yukawa couplings, the neutralino mixing matrix and the sfermion left-right mixing angles.

The angular distribution of the decay chain (1) is given as

$$\frac{d^3\Gamma}{d\cos\theta_{\tilde{l}}\, d\cos\theta_{\tilde{\chi}^0_1}\, d\phi_{\tilde{\chi}^0_1}} = \frac{1}{8\pi}\Gamma(\tilde{q}_\beta \to q\tilde{\chi}^0_2) Br(\tilde{\chi}^0_2 \to l^\pm_1 \tilde{l}^\mp_\alpha) Br(\tilde{l}^\mp_\alpha \to l^\mp_2 \tilde{\chi}^0_1) \times [1 \mp A(l)\cos\theta_{\tilde{l}}]\,, \quad (3)$$

$$A(l) = \frac{|L^q_{2\beta}|^2 - |R^q_{2\beta}|^2}{|L^q_{2\beta}|^2 + |R^q_{2\beta}|^2} \cdot \frac{|L^l_{2\alpha}|^2 - |R^l_{2\alpha}|^2}{|L^l_{2\alpha}|^2 + |R^l_{2\alpha}|^2}, \quad (4)$$

where Γ and Br denotes the decay width and branching ratio, respectively. $\theta_{\tilde{l}}$ is the angle between the momenta of the quark and the lepton l_1 in the $\tilde{\chi}^0_2$ rest frame, $\theta_{\tilde{\chi}^0_1}$ is the angle between the two lepton momenta in the slepton rest frame, and $\phi_{\tilde{\chi}^0_1}$ is the angle between the decay planes of $\tilde{q} \to q l^\pm_1 \tilde{l}^\mp$ and $\tilde{\chi}^0_2 \to l^\pm_1 l^\mp_2 \tilde{\chi}^0_1$. Since squark and slepton decays are spherically symmetric in the rest frames of the decaying particles, the angular distribution is flat over $\cos\theta_{\tilde{\chi}^0_1}$ and $\phi_{\tilde{\chi}^0_1}$. The $\theta_{\tilde{l}}$ dependence, which comes from the polarization of $\tilde{\chi}^0_2$, eventually shows up in the quark-lepton invariant mass $m(ql)$ distribution. Since l_1 from the neutralino decay and l_2 from the slepton decay are indistinguishable, we study the charge asymmetry between the $m(ql^\pm)$ distributions taking both l_1 and l_2 into account [3]. The $m(ql^+)$ distribution consists of l^+_1 from $\tilde{\chi}^0_2 \to l^+_1 \tilde{l}^-$ and l^+_2 from $\tilde{\chi}^0_2 \to l^-_1 \tilde{l}^+ \to l^-_1 l^+_2 \tilde{\chi}^0_1$.

We consider a "typical" case of the mSUGRA, where the wino component dominates $\tilde{\chi}^0_2$ and the bino component dominates $\tilde{\chi}^0_1$. We can safely neglect the left-right mixing of the squarks because the process we consider is the decay of the first generation squark. The first decay process $\tilde{q} \to q\tilde{\chi}^0_2$ in Eq. (1) occurs predominantly through the $\tilde{q}_L$-q-$\tilde{W}$ coupling so that the first factor of the right-hand side of Eq. (4) is very close to unity.

As for the slepton mass matrix, the right-handed slepton mass parameter becomes smaller than the left-handed one due to the running effect. Therefore the lighter slepton, $\tilde{l}_1$, is $\tilde{l}_R$-like in the most of the parameter space. In the $\tilde{l}_1$-l-$\tilde{\chi}^0_2$ couplings, the main component of R^l_{21} comes from the U(1) gauge coupling and is approximately universal for the lepton flavor. On the other hand, the SU(2)×U(1) gauge coupling term in L^l_{21} appears only through the left-right mixing of the sleptons, which is proportional to the lepton mass, so that L^l_{21} depends on the lepton flavor.

For the (s)electron, L^e_{21} is negligibly small compared to R^e_{21} and the charge asymmetry is maximal ($A(e) \approx -1$). The effect of the left-right mixing and the Yukawa coupling is quite significant for the (s)tau mode. The mixing angle of the stau is typically $O(1)$ for large $\tan\beta$. Then L^τ_{21} dominate over R^τ_{21} and the behavior of the charge asymmetry is opposite to the electron case. The left-right mixing effect may be observed even in the (s)muon case, since L^μ_{21} is enhanced by $O(m_\mu/m_e)$ compared to L^e_{21}. For a relatively large $\tan\beta$, it is possible that L^μ_{21} and R^μ_{21} are of the same order of magnitude.

3. Numerical Results

We perform a Monte Carlo simulation for mSUGRA benchmark points SPS1a and

SPS3 [4]. SPS1a is given by $m_0 = 100$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$ GeV, $\tan\beta = 10$ and $\mu > 0$[b]. Here $m(\tilde{l}_2) > m(\tilde{\chi}^0_2) > m(\tilde{l}_1)$ so that only $\tilde{l}_1$ contributes to the decay chain. We also show the results for the point with $\tan\beta = 20$ and other parameters are the same as those of SPS1a. The $\tilde{\mu}$ left-right mixing effect becomes significant for this point. Parameters for SPS3 are $m_0 = 90$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$. In this case, $m(\tilde{\chi}^0_2) > m(\tilde{l}_2) > m(\tilde{l}_1)$ and $\tilde{\chi}^0_2 \to \tilde{l}_2$ dominates over $\tilde{l}_1$ process in the kinematically allowed region because the SU(2) gauge coupling component in L^l_{22} dominates over other couplings.

We generated 3×10^6 events for SPS1a and SPS3. This corresponds to $\int \mathcal{L}dt = 58$ fb^{-1} and 600 fb^{-1} for SPS1a and SPS3, respectively. The mass spectrum, couplings and branching ratios are calculated by ISAJET [5] and interfaced to HERWIG [6] by using ISAWIG program [7]. The events are studied using the fast detector simulator ATLFAST [8]. See Ref. [1] for detail of the simulation analysis.

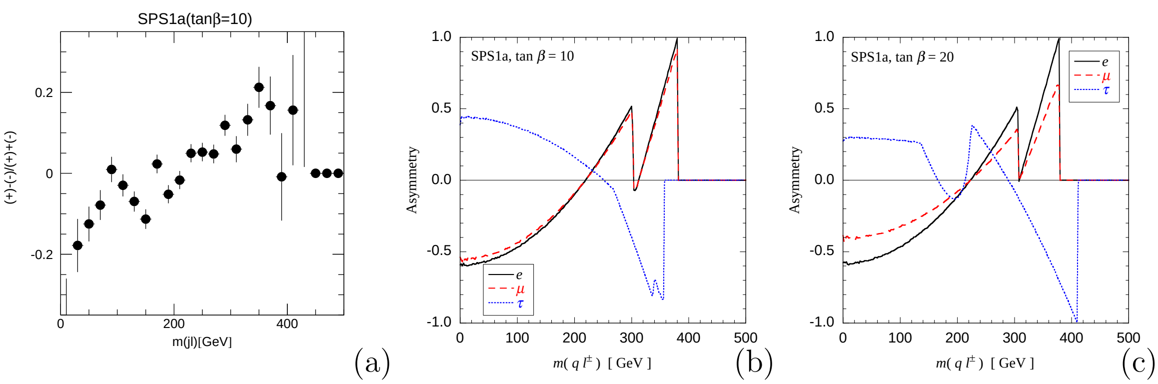

Figure 1: (a) The reconstructed charge asymmetry for SPS1a. (b) The calculated charge asymmetry for SPS1a. (c) The calculated charge asymmetry for SPS1a with $\tan\beta = 20$.

Fig. 1 shows the charge asymmetry defined by $[N(ql^+) - N(ql^-)]/[N(ql^+) + N(ql^-)]$, for SPS1a. (a) is the plot of the simulation data, where e and μ events are combined. Since ISAJET neglect Yukawa couplings for e and μ, the e-μ non-universality discussed in the previous section is not taken into account in the event generations. (b) and (c) are calculated theoretical values for $\tan\beta = 10$ and 20, respectively. We see that (a) and (b) are qualitatively similar: the distribution shows negative asymmetry for small $m(jl)$ region and positive asymmetry near $m(jl)$ endpoint. The main source of the discrepancy in the magnitudes of the asymmetries between (a) and (b) is understood as the dilution due to the anti-squark events. The dilution factor $[N(\tilde{q}) - N(\tilde{q}^*)]/[N(\tilde{q}) + N(\tilde{q}^*)]$ is evaluated as 50% and 58% for SPS1a and SPS3, respectively, in the present simulations. In (b) and (c), we see the lepton flavor dependence of the charge asymmetry discussed in the previous section. The asymmetry for τ mode is opposite to that for e and μ for both cases, and e-μ difference is as large as 30% for $\tan\beta = 20$ case (c). Charge asymmetry for SPS3 is shown in Fig. 2. In the $m(ql) < 200$ GeV region, the behavior of the asymmetry is similar for all the lepton flavor, since the lepton mainly comes from the $\tilde{\chi}^0_2 \to l_1\tilde{l}_2$ decay.

[b] m_0, $M_{1/2}$ and A_0 are the common scalar mass, the gaugino mass and the trilinear scalar coupling at the GUT scale, respectively, $\tan\beta = \langle h_2\rangle/\langle h_1\rangle$ and μ is the Higgsino mass parameter.

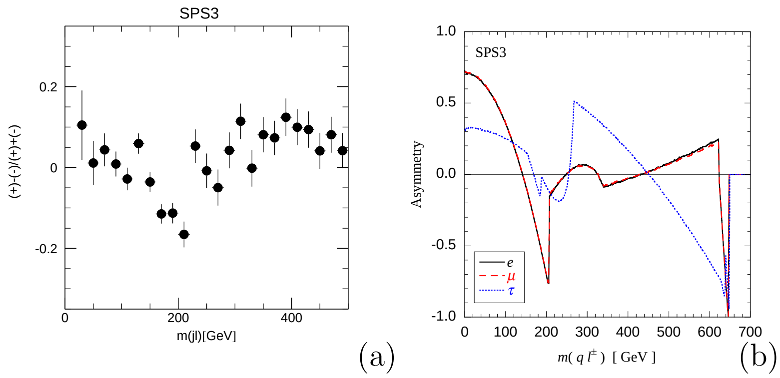

Figure 2: (a) The reconstructed charge asymmetry and (b) The calculated charge asymmetry for SPS3.

Also the branching ratio of $\tilde{\chi}^0_2 \to l\tilde{l}_1$ depends on the lepton flavor. The decay width for $\tau\tilde{\tau}_1$ mode is much larger than those for $e\tilde{e}_1$ and $\mu\tilde{\mu}_1$, and $\Gamma(\tilde{\chi}^0_2 \to \mu\tilde{\mu}_1) > \Gamma(\tilde{\chi}^0_2 \to e\tilde{e}_1)$ is possible for large $\tan\beta$.

4. Conclusion

In this work, we study the charge asymmetry of $m(jl^\pm)$ distribution in the cascade decay $\tilde{q} \to q\tilde{\chi}^0_2 \to ql\tilde{l} \to qll\tilde{\chi}^0_1$, in order to study the LHC capability of providing an information on the chirality structure of the sfermion-fermion-neutralino interaction. We find that the charge asymmetry is significant for two representative mSUGRA points, SPS1a and SPS3. Taking the left-right mixing of the sleptons into account, we show that the charge asymmetry and the branching ratio of $\tilde{\chi}^0_2 \to l\tilde{l}_1$ is flavor non-universal and that the LHC can detect e-μ non-universality at SPS1a($\tan\beta = 10$-20) for $\int dt\mathcal{L} = 300$ fb^{-1} if detection efficiencies of e and μ are understood at the LHC.

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